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Part 1. CARBON MONOXIDE STUDY - SEATTLE, WASHINGTON

OCTOBER 6 - NOVEMBER 2, 1977

EXECUTIVE SUMMARY

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SURVEILLANCE AND ANALYSIS DIVISION

FOR

AIR PROGRAMS BRANCH

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DECEMBER 1978

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PREFACE

Under the Clean Air Act of 1970 the U.S. Environmental Protection Agency has established standards for carbon monoxide in air external to buildings to which the public has access. In a number of cities, including Seattle, these standards have not yet been attained. Plans to achieve the standards are now required under the Clean Air Act Amendments of 1977 (PL 95-95). It is hoped that the material presented in this report will assist in achieving attainment of the standards.

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Abbreviations and Symbols

AM - The four-hour interval from 10:00 a.m. to 2:00 p.m.

PM - The four-hour interval from 2:00 p.m. to 6:00 p.m.

AVC - The eight-hour average CO concentration for the 10:00 a.m. to 6:00 p.m. sample collected at an EPA special study site

AVSxxx- The eight-hour average CO concentration for the 10:00 a.m. to 6:00 p.m. period from continuous non-dispersive infra-red (NDIR) measurements at a permanent monitor where "xxx" is an abbreviation for the particular monitor

s/o - "South of" as in Second Avenue s/o University Street

e/o - "East of" as in James Street e/o Fourth Avenue

R.AVC.AVSx - Ratio of eight-hour averages at the same time for a study site and for a permanent monitor (where "x" is the first letter abbreviation of the abbreviations listed below)

JAM - Permanent monitor on James Street (north side) e/o Fourth Avenue (the Municipal Building)

UNI - Permanent monitor on Second Avenue (west side) s/o University Street (near McPhearson's Leather Co.)

PIK - Permanent monitor on Fourth Avenue (east side) s/o Pike Street (Fourth and Pike Building)

SIN - Permanent monitor on Pike Street (south side) e/o Fourth Avenue (near Singer's)

FIR - Permanent monitor on Second Avenue (west side) s/o Main Street (Fire Station No. 10 near Pioneer Square)

Exceedence of Standard* - An eight-hour average CO concentration exceeding 9.0 ppm

Violation of Standard - The second eight-hour, non-overlapping, running average CO concentration in a year to exceed 9.0 ppm

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* This report discusses only the standard for the eight-hour average and does not discuss the standard for one-hour average CO concentrations.

INTRODUCTION

Frequent violations of the national ambient air quality standard* for eight-hour average carbon monoxide (CO) concentrations have occurred at several of the continuous monitors operated in downtown Seattle by the Washington State Department of Ecology. However, more information on the severity of the CO problem and its spatial distribution in the downtown area was desired to assist in selecting candidate sites for additional routine monitoring and evaluating the extent to which the permanent monitors represent sites elsewhere in the central business district. The levels of CO encountered by the population as downtown pedestrians and as indoor occupants were also of interest. A study was planned and conducted to address these needs. This report (Part 1) presents the major results and conclusions. A more detailed description of the methods, additional discussion and analysis and data obtained in this study appear in a separate volume (Part 2).

SUMMARY

In 1977, a 20-day study involving 36 outdoor sites, five indoor sites, and two pedestrian walking routes was conducted in downtown Seattle during

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* Standards for carbon monoxide which are not to be exceeded more than once per year are 9.0 ppm (eight-hour average) and 35.0 ppm (one-hour average). See 42 FR 8186, Federal Register, April 30, 1971.

October-November which is during part of the season when high carbon monoxide levels frequently occur. The purpose of this study was to obtain more information on the magnitude and spatial extent of the carbon monoxide problem which would aid evaluation of the extent to which the existing permanent monitors represent locations elsewhere in the central business district and would assist in selection of candidate sites for routine monitoring. On each week-day, two four-hour bag samples were collected from about 10:00 a.m. to 2:00 p.m. (AM sample) and about 2:00 p.m. to 6:00 p.m. (PM sample) at 33 of the outdoor sites and two or three of the indoor sites simultaneously. Technicians collected bag samples of air on two pedestrian walking routes over two to four hours during the AM and PM periods.

Data are summarized in bar charts of the measurement distribution for each site and each day of the study period, in histogram-maps showing the spatial distribution of carbon monoxide, and in tables. Results from the study sites were compared in several ways with data from the permanent monitors. Comparisons were also made between study sites along the same corridor, between indoor sites and adjacent outdoor sites, and between the two pedestrian routes. Eight-hour averages were compared with the 9.0 ppm standard.

The study results indicate that the carbon monoxide problem is not restricted to the immediate vicinity of the permanent monitors in the downtown commercial district. The permanent monitoring network was

generally representative of the high concentrations but not the highest frequency of violations which occurred in the study area. More frequent exceedences of the standard occurred on Sixth Avenue south of Union (site 19) than at any of the permanent monitoring sites during this study. CO values exceeded the 9.0 ppm eight-hour standard at some study sites on days when the highest eight-hour average of the permanent monitors measured on that day was (1) below the standard and (2) less than two-thirds of the highest average observed at the maximum study site on that day. Increases in carbon monoxide at indoor sites frequently coincided with increases at outdoor sites. At times, some of the indoor population was exposed to eight-hour average concentrations above 9.0 ppm, which is the outdoor standard.

Routine monitoring of peak concentrations should consider the monitoring site on Fourth Avenue south of Pike Street. Planning for future studies should consider the need for related data on traffic characteristics coupled with meteorological data.

CONCLUSIONS AND RECOMMENDATIONS

The major conclusions of a 20-day study conducted in Seattle during about 10:00 a.m. to 6:00 p.m. on week-days of October - November 1977 are:

1. The severity of the carbon monoxide problem in the central business district as measured by the highest eight-hour average concentrations (compared without regard to the day in which they occurred) was adequately represented by the permanent monitor at Fourth Avenue south of Pike Street. However, the permanent monitoring network did not represent the highest frequency of exceedences of the eight-hour standard during the twenty-day period.

   - During the study period, the highest 10:00 a.m. to 6:00 p.m. average of all the study sites was 16.1 ppm and it occurred on October 28 at site 1 on First Avenue south of Pike Street. This was essentially the same as the highest of all the permanent monitors during the study period (15.8 ppm on October 14th at PIK, the permanent monitor on Fourth Avenue south of Pike Street).

   - About 17% of the study sites (6 out of 36) experienced at least one eight-hour average concentration within 2.0 ppm of the highest 10:00 a.m. to 6:00 p.m. average of all the permanent monitors. (Note that these are comparisons of the maximums during the 20-day study period and did not necessarily occur on the same day.)

- The highest eight-hour average at each of these six study sites (sites 1, 5, 7, 9, 10, and 19) exceeded the maximum at the Second and University monitor, 12.8 ppm, which was the next highest reading from a permanent monitor. (Again, this comparison is of maximums during the 20-day study period, regardless of the day on which they occurred.)

2. The permanent monitoring network was not representative of the highest frequency of exceedences of the 9.0 ppm standard within the study area for this twenty-day period.

   - The eight-hour standard was exceeded at one or more study sites on 80% of the study days (16 out of 20). Exceedences at one or more of the permanent monitors occurred on 45% (9 out of 20) of the sampled days.

   - The most frequent exceedences of the 9.0 ppm standard were observed at site 19 on Sixth Avenue south of Union Street (80% of the days). Considering all study sites, this site had the highest eight-hour average of the day more frequently than any other site (on 8 of the 20 days of the study). The highest eight-hour average at site 19 over the twenty-day study interval (13.9 ppm on October 28) was exceeded at only four study sites. These sites (1, 7, 9, and 10) also experienced their highest values of the twenty-day interval on October 28 (16.1, 14.5, 14.0, and 15.0 ppm, respectively).

- The frequency of exceedences at the permanent monitors ranged from 0% at the Fire Station on Second Avenue south of Main Street (FIR) to 40% of the sampled days at the monitoring site on Fourth Avenue south of Pike (PIK).

- On all but two days, the highest eight-hour concentration of those measured at the permanent monitors for 10:00 a.m. to 6:00 p.m. was exceeded by that at one or more study sites.

- During the survey, the second-highest eight-hour average for 10:00 a.m. to 6:00 p.m. for any permanent monitor (13.6 ppm on 10/28/77 at PIK on Fourth Avenue south of Pike Street) was exceeded by one study site's second-highest average (15.0 ppm on 10/21/77 at site 10 on Fourth Avenue south of Union).

3. The CO problem occurred throughout the downtown commercial district but concentrations were lower at some locations.

   - For 47% of the study sites (17 of 36), the 10:00 a.m. to 6:00 p.m. eight-hour average exceeded the 9.0 ppm standard more than once.

   - For 14% of the study sites (5 out of 36), the 10:00 a.m. to 6:00 p.m. eight-hour average equalled or exceeded the 9.0 ppm standard exactly once.

- For 39% of the study sites (14 out of 36) including some locations in parks and other areas of expected low concentrations, eight-hour averages for 10:00 a.m. to 6:00 p.m. did not exceed the 9.0 ppm standard during the 20-day study.

- The highest eight-hour average of the day did not always occur at the same sites. On 90% of the days (18 of 20), the highest average was measured at a study site rather than at a permanent monitor. Sites 1, 5, 7, 10, 19, 22, 29, and 36 were study sites which were "maximum" on at least one day considering permanent monitors as well as study sites. Site 19 was highest on 35% of the days and tied for highest with PIK on 5% of the days; each of the sites 1, 7, 10, and 22 was highest on 10% of the days; and each of the sites 5, 29, and 36 was highest on 5% of the days. The permanent monitor PIK, was highest on 5% of the days.

- Relatively low average concentrations were observed at sites 18, 21, and 35 which are closer to the freeway than the other study sites. For these sites, the averages of all eight-hour values were 4.2, 3.8, and 3.6 ppm respectively.

- On four of the days when no violations were observed at the permanent monitors, the maximum study site's eight-hour average exceeded 9.0 ppm and was more than 1.5 times greater than at the maximum permanent monitor.

- When concentrations exceeded the standard at the permanent monitors they were exceeded at a number of other locations.

4. Changes in CO concentrations at outdoor sites frequently coincided with changes in CO concentrations at indoor sites, but the relationship between indoor and outdoor values was not constant.

   - Concentrations were usually lower indoors than at the selected adjacent outdoor site.

   - Indoors, the eight-hour average concentration of carbon monoxide exceeded 9.0 ppm at one of the five sites (SIN 1) on Fourth Avenue south of Union Street.

5. Pedestrians were probably exposed to average CO concentrations exceeding 9.0 ppm over four or more hours at times.

   - For sampling periods between two to four hours, concentrations ranged from 1.1 ppm to 11.9 ppm.

   - For sequential or nearly sequential sampling periods totalling two to four or more hours, average concentrations were equal to or above 9.0 ppm on three of the 20 days. (On most days, sampling was not conducted for a consecutive eight-hour interval on the pedestrian routes as personnel were required for other duties.)

It is recommended that:

1. The carbon monoxide problem in downtown Seattle be considered an areawide problem in the central business district, as opposed to a few isolated "hot spots".

2. Increased local source emissions be avoided in areas where violations have been observed unless a reduction in the background concentrations which is more than sufficient to offset the increase and attain and maintain the National Ambient Air Quality Standards can be demonstrated.

3. Concentrations at the permanent monitoring network above 9.0 ppm be considered as indicative of concentrations equally high and possibly higher elsewhere in the study area at the same time. However, concentrations at the permanent monitors below the 9.0 ppm standard on a particular day should not be considered as assurance that air quality standards are being met throughout the study area on that same day.

4. The permanent monitor on the east side of Fourth Avenue south of Pike Street (PIK) be considered as a candidate site to represent peak carbon monoxide concentrations in downtown Seattle for routine monitoring.

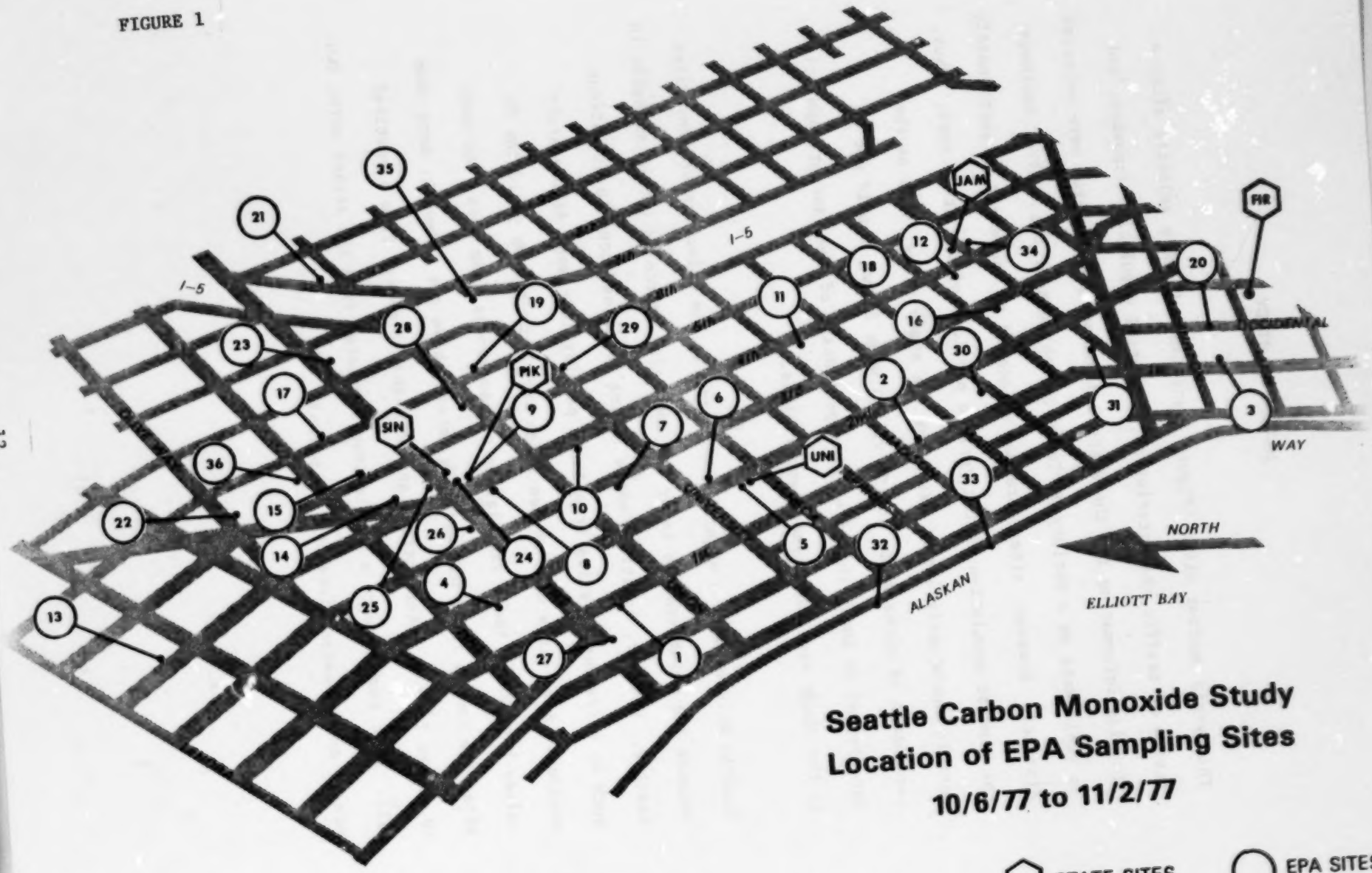
5. Planning for future studies to aid development and/or revision of control strategies to attain the natural ambient air quality standard should consider the possible utility of ancillary data on traffic and meteorological characteristics to aid data interpretation.

METHOD OF STUDY

Thirty-six outdoor sites (Figure 1 and Table 1) were selected after a review of traffic characteristics, potential population exposure, and planning information for the Seattle downtown area. Sites were selected to yield data on a variety of locations throughout the central business district. However, sites were not allocated to represent proportionately the land or population of the various portions of the study area. Thus, certain characteristics of data from the study sites, such as the percentage of sites where low CO values were found, should not be interpreted to imply that a similar percentage of the land or population in the study area experienced such values.

Traffic volumes were a significant factor in the selection of many sites because the motor vehicle is by far the major source of carbon monoxide in Seattle. However, locations where idling vehicles occur in situations such as entrances or exits from large parking lots were deliberately avoided. Some sites were chosen which were expected to yield low CO values because of their ventilation or remoteness from cars. At each site, the sample inlet was about 3½ meters above the sidewalk, more than 10 meters from an intersection, and more than 2 meters from a vertical wall. Most samples were a little over one meter from the street curb; two were at much greater distances (in parks).

FIGURE 1


I-5
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1
UNI
5
32
11
18
12
JAM
34
16
30
2
31
20
FIR
3
33
WAY
NORTH
ALASKAN
ELLIOTT BAY
Seattle Carbon Monoxide Study
Location of EPA Sampling Sites
10/6/77 to 11/2/77
STATE SITES
EPA SITES

TABLE 1.

SEATTLE CO STUDY - Oct. 6 to Nov. 2, 1977

SITE IDENTIFICATION

SITE #	LOCATION	SIDE OF STREET
1	1st s/o Pike	W
2	1st s/o Madison	E
3	1st s/o Washington	E
4	2nd s/o Pine	W
5	2nd s/o University	W
6	2nd s/o University	E
7	3rd s/o Union	W
8	4th s/o Pike	W
9	4th s/o Pike	E
10	4th s/o Union	W
11	4th s/o Madison	W
12	4th s/o Cherry	W
13	4th s/o Lenora	E
14	4th s/o Pine	E
15	5th s/o Pine	E
16	3rd s/o Cherry	W
17	6th s/o Pine	E
18	6th s/o Columbia	W
19	6th s/o Union	E
20	Occidental s/o Washington	S
21	9th s/o Union	E
22	Olive e/o 5th	S
23	Pike e/o 7th	S
24	Pike e/o 4th	S
25	Pike e/o 4th	N
26	Pike e/o 3rd	N
27	Pike w/o 1st	S
28	Union e/o 5th	N
29	University e/o 5th	S
30	Columbia e/o 1st	N
31	James e/o 1st	N
32	Alaskan Way s/o University	W
33	Alaskan Way s/o Madison	W
34	James e/o 4th	S
35	Seneca e/o 6th	N
36	Pine e/o 5th	N
PERMANENT MONITORS	(STATE SITES)	
JAM	JAMES E/O 4TH	N
UNI	2ND S/O UNIVERSITY	W
SIN	PIKE E/O 4TH	S
PIK	4TH S/O PIKE	E
FIR	2ND S/O MAIN	W

Each week-day, air was collected into a bag during two sequential periods (about 10:00 a.m. to 2:00 p.m. and about 2:00 p.m. to 6:00 p.m.) so that an eight-hour average could be calculated for comparison with the National Ambient Air Quality Standard of 9.0 ppm which is not to be exceeded more than once per year. Samples were obtained during October 6 through November 2, 1977 on week-days from about 10:00 a.m. to 6:00 p.m. because this period of the day seemed most likely to have high carbon monoxide levels based on data from the permanent monitors. This period of the day appeared to be fairly representative of the highest eight-hour concentrations since the daily maximum eight-hour averages at the James Street and the Fourth and Pike state monitors (JAM and PIK) were usually within 1 ppm of the 10:00 a.m. to 6:00 p.m. average during the days of the study. Carbon monoxide in the study samples was analyzed by an electro-chemical oxidation method, (Ecolyzer). Continuous analysis of air at the indoor sites (in addition to bag sampling indoors and at the adjacent outdoor site) monitored the daily pattern of indoor carbon monoxide levels.

Indoor sites representing exposure situations in downtown buildings within a few blocks of the permanent monitors at Fourth and Pike included a small retail shop, a hotel, two office buildings and a medical building. At all locations, care was taken to avoid non-vehicle sources of carbon monoxide such as tobacco smoke in the immediate vicinity of the sampler or fuel combustion from building heating systems. The nearest adjacent outdoor site was the basis for comparison.

RESULTS AND DISCUSSION

Outdoor Sites

The relative severity of the carbon monoxide problem at various outdoor sites during the selected time period is indicated by several measures. Maximum and second-highest eight-hour averages, the frequency of exceedences observed at each site and maximum four-hour AM (10:00 a.m. to 2:00 p.m.) and PM (2:00 p.m. to 6:00 p.m.) averages in Table 2 may be compared with values based on measurements at the permanent monitoring sites. Data distributions for each site's eight-hour (10:00 a.m. to 6:00 p.m.) averages are compared in Figure 2. Figures 3, 4, and 5 illustrate the spatial variation of the data in Table 2 on maps of Seattle.

In general, the lowest eight-hour values occurred at the sites adjacent to Elliot Bay (sites 32 and 33), and the park sites (sites 20 and 35). The relatively good ventilation possible in these areas and, in the case of the park sites, the greater distance from the nearest roadway may have contributed to the lower concentrations at these sites.

Depending on the purpose of the analysis, different measures are appropriate for examination of the representativeness of the existing permanent monitoring network. Day-by-day similarities are not required to compare the necessary reduction of carbon monoxide levels implied by data from two different sites. The relationships between data at the permanent monitors and at other sites are not necessarily the same from day-to-day.

Table 2. Maximum Values from Thirty-Six Sites and Five Permanent Monitors
(Carbon Monoxide in PPM)

Site	Maximum AM 10 AM - 2 PM	Maximum PM 2 PM - 6 PM	Maximum AVC 10 AM - 6 PM	% AVC GT 9.0	Ratio.1[1/] James	Ratio.1 University	Ratio.1 Singer	Ratio.1 Pike	Ratio.1 Fire Station	Date of Maximum AVC
1	12.4	19.9	16.1	33.0	-	1.3	1.3	1.2	2.5	10/28/77
2	11.9	8.0	7.4	0.0	-	-	0.9	1.0	-	10/27/77
3	13.8	13.6	11.0	11.0	-	0.9	0.9	0.8	1.7	10/28/77
4	10.6	13.0	11.8	22.0	-	0.9	1.0	0.9	1.8	10/28/77
5	17.0	14.9	13.7	35.0	-	-	1.6	1.8	-	10/27/77
6	7.8	8.7	7.9	0.0	0.8	1.8	1.3	0.7	-	10/19/77
7	16.8	12.2	14.5	57.0	-	1.1	1.2	1.1	2.8	10/28/77
8	10.9	14.5	10.4	19.0	2.2	1.0	1.1	0.9	-	10/21/77
9	10.9	17.1	14.0	32.0	-	1.1	1.1	1.0	2.1	10/28/77
10	14.4	17.8	15.0	33.0	-	1.2	1.2	1.1	2.3	10/28/77
11	12.6	12.0	11.4	26.0	1.2	1.6	1.7	-	2.3	10/10/77
12	10.0	10.5	10.3	7.0	-	0.8	0.8	0.8	1.6	10/28/77
13	8.0	9.0	7.0	0.0	0.6	1.1	1.2	0.4	-	10/14/77
14	6.5	8.1	7.3	0.0	-	0.6	0.6	0.5	1.1	10/28/77
15	11.0	11.1	10.3	6.0	-	0.8	0.8	0.8	1.6	10/28/77
16	10.4	11.5	10.0	17.0	1.7	0.9	1.1	1.0	1.7	10/06/77
17	15.4	12.8	12.0	47.0	-	-	1.4	1.6	-	10/27/77
18	7.5	7.8	7.4	0.0	-	0.6	0.6	0.5	1.1	10/28/77
19	13.6	15.9	13.9	80.0	-	1.1	1.1	1.0	2.1	10/28/77
20	5.5	5.2	4.4	0.0	-	0.3	0.4	0.3	0.7	10/28/77
21	8.0	6.1	7.1	0.0	-	0.6	0.6	0.5	1.1	10/28/77
22	13.7	18.6	11.2	26.0	-	-	1.3	1.6	-	10/27/77
23	12.9	14.0	11.4	11.0	2.4	1.0	1.2	1.0	-	10/21/77
24	10.7	12.0	10.7	12.0	-	0.8	0.9	0.8	1.6	10/28/77
25	12.0	9.1	9.3	5.0	-	0.7	0.8	0.7	1.4	10/28/77
26	8.0	10.9	8.6	0.0	0.8	1.4	1.5	0.5	0.8	10/14/77
27	7.7	9.5	8.5	0.0	1.8	0.8	0.9	0.7	-	10/21/77
28	10.1	13.0	10.2	27.0	0.9	1.6	1.7	0.6	-	10/14/77
29	11.0	14.1	10.4	5.0	-	0.8	0.8	0.8	1.6	10/28/77

Table 2. (continued)

Site	Maximum AM 10 AM - 2 PM	Maximum PM 2 PM - 6 PM	Maximum AVC 10 AM - 6 PM	% AVC GT 9.0	Ratio.1 James[2]	Ratio.1 University[3]	Ratio.1 Singer[4]	Ratio.1 Pike[5]	Ratio.1 Fire Station[6]	Date of Maximum AVC
30	7.0	9.0	7.9	0.0	0.7	1.3	1.3	0.5	-	10/14/77
31	7.1	7.9	7.2	0.0	1.0	0.8	-	0.8	1.2	10/28/77
32	5.5	5.2	5.4	0.0	0.6	0.8	0.8	-	1.1	10/10/77
33	5.0	4.5	4.6	0.0	0.5	0.7	0.7	-	0.9	10/10/77
34	9.3	11.9	10.3	6.0	-	0.8	0.8	0.8	1.6	10/28/77
35	7.8	5.5	5.7	0.0	-	-	0.7	0.7	-	10/27/77
36	11.6	12.9	11.4	41.0	1.2	1.6	1.7	-	2.3	10/10/77
JAM[2]	10.0	12.3	11.1	27.0	1.0	1.8	1.9	0.7	-	10/14/77
UNI[3]	11.0	14.5	12.8	15.0	-	1.0	1.0	0.9	2.0	10/28/77
SIN[4]	10.8	13.8	12.3	16.0	-	1.0	1.0	0.9	1.9	10/28/77
PIK[5]	13.5	18.0	15.8	40.0	1.4	2.5	2.7	1.0	-	10/14/77
FIR[6]	6.0	7.8	6.5	0.0	-	0.5	0.5	0.5	1.0	10/28/77

Footnotes

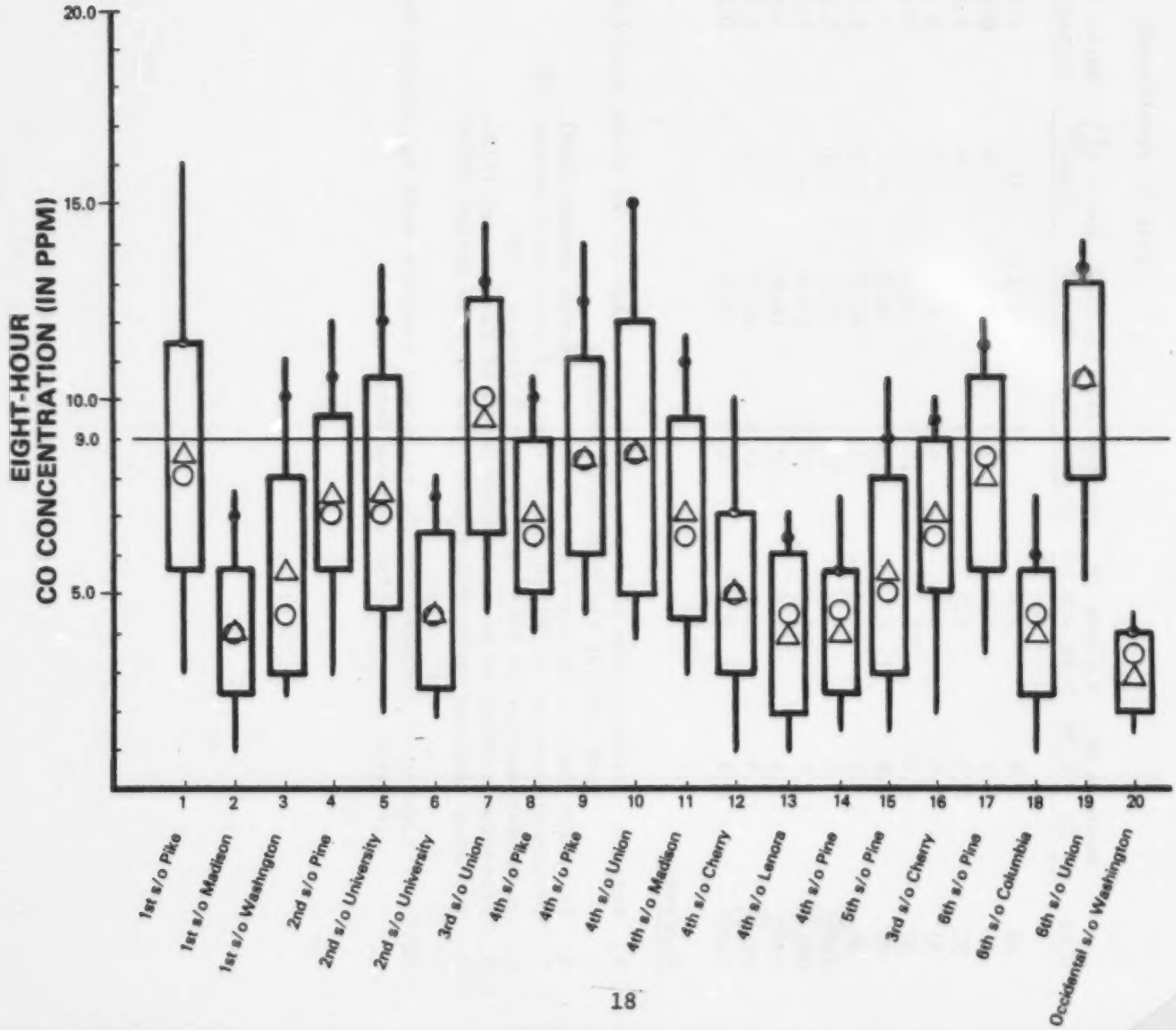
1. Ratio.1 - Ratio of the maximum eight-hour average at the study site to the eight-hour average at the same time (and day) at the permanent monitor.
2. Permanent monitor on James Street east of Fourth Avenue (JAM).
3. Permanent monitor on Second Avenue south of University Avenue (UNI).
4. Permanent monitor on Pike east of Fourth Avenue (SIN).
5. Permanent monitor on Fourth Avenue south of Pike Street (PIK).
6. Permanent monitor on Second Avenue south of Main Street (FIR).

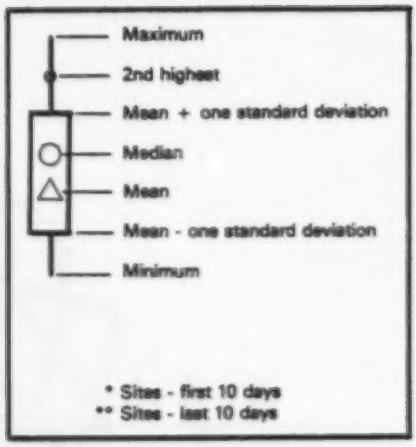
NOTE: Eight-hour averages for the permanent monitors were calculated from hourly averages (eight values). No estimates were made for missing data.

Seattle Carbon Monoxide
October 6 to November 2, 1977
(Weekdays Only)

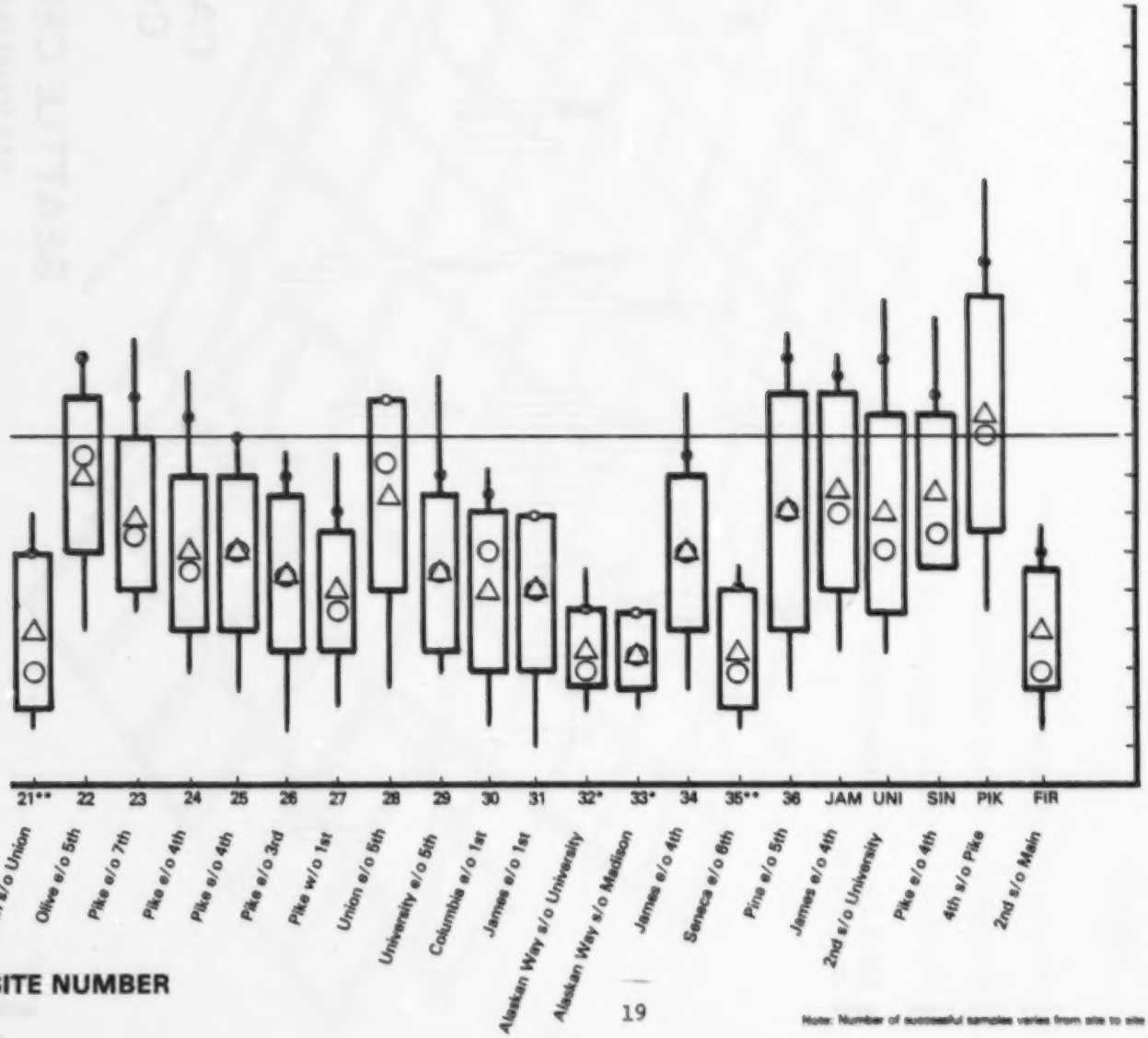
FIGURE 2

Characteristics of Weekday Carbon Monoxide Average Concentrations for an Eight-Hour Period (10:00 A.M. to 6:00 P.M.) at Each Site.





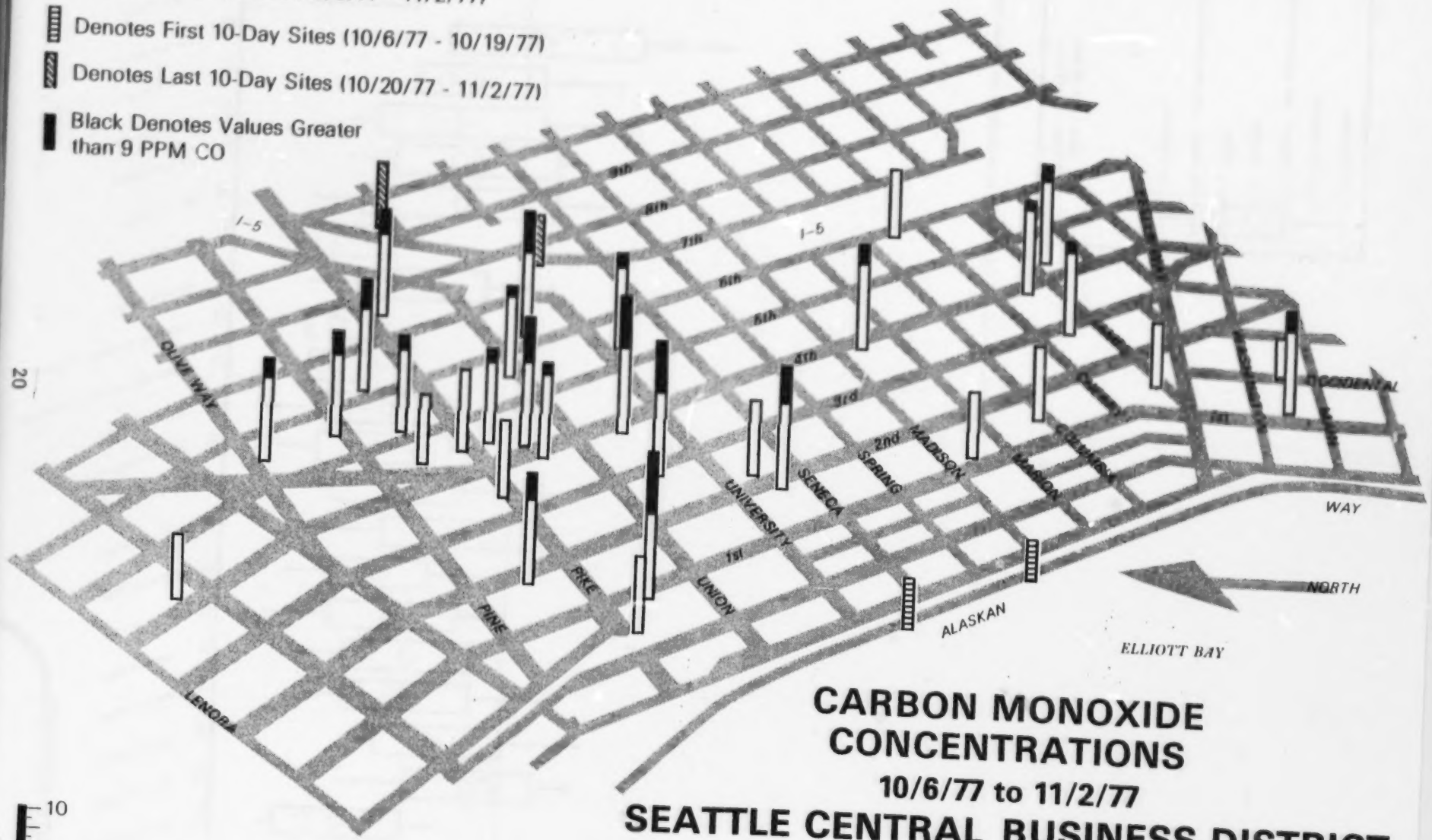
Standard not to be exceeded more than once per year



SITE NUMBER

Note: Number of successful samples varies from site to site

FIGURE 3



CARBON MONOXIDE CONCENTRATIONS

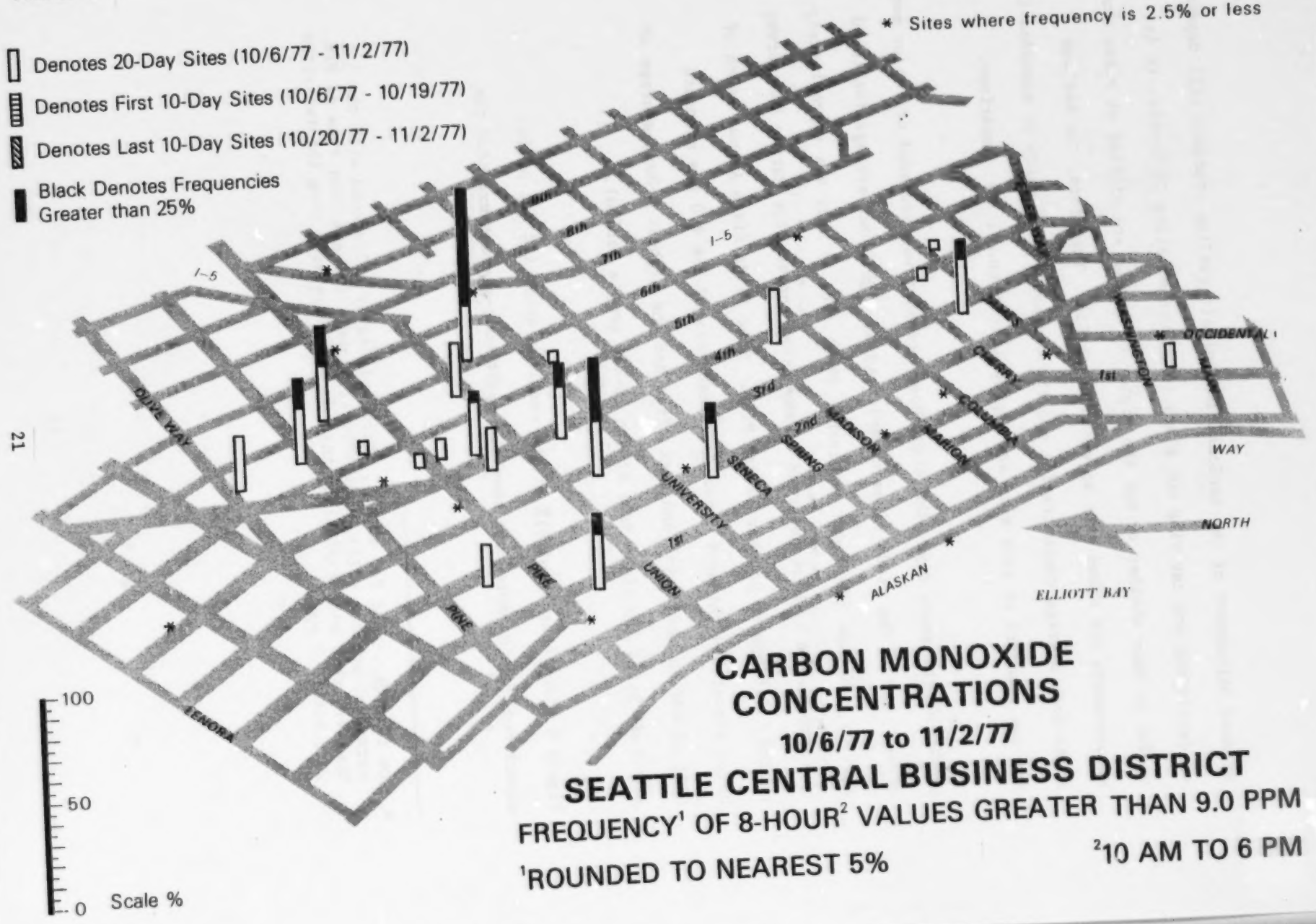
10/6/77 to 11/2/77

SEATTLE CENTRAL BUSINESS DISTRICT

MAXIMUM 8-HOUR[1] VALUES FOR ENTIRE SAMPLING INTERVAL

[1]10 AM TO 6 PM

FIGURE 4



CARBON MONOXIDE CONCENTRATIONS

10/6/77 to 11/2/77

SEATTLE CENTRAL BUSINESS DISTRICT

FREQUENCY[1] OF 8-HOUR[2] VALUES GREATER THAN 9.0 PPM

[1]ROUNDED TO NEAREST 5%

[2]10 AM TO 6 PM

Because attainment of the national ambient air quality standard will depend on developing and carrying out plans to reduce existing CO levels, it is useful to know whether or not the higher CO levels are similar at sites when measurements are taken over an extended period. Therefore, the maximum eight-hour average concentration and the frequency with which it exceeded the 9.0 ppm standard at each site are appropriate measures for comparison.

On 80% of the study days, the eight-hour standard was exceeded at one or more sites. One of the study sites experienced an eight-hour average for 10:00 a.m. to 6:00 p.m. (16.1 ppm on October 28 at site 1) that was approximately the same as the highest observed at any permanent monitor during the survey period (15.8 ppm on October 14* at PIK). Site 19 on Sixth Avenue south of Union Street had the most frequent exceedences of the 9.0 ppm standard (80% of the sampled days) and most often had the highest 8-hour average of all study sites (on eight days of the 20-day sample period).

Figure 4 shows that about 61% of the sampling sites (22 out of 36) experienced one or more days when the eight-hour average exceeded the

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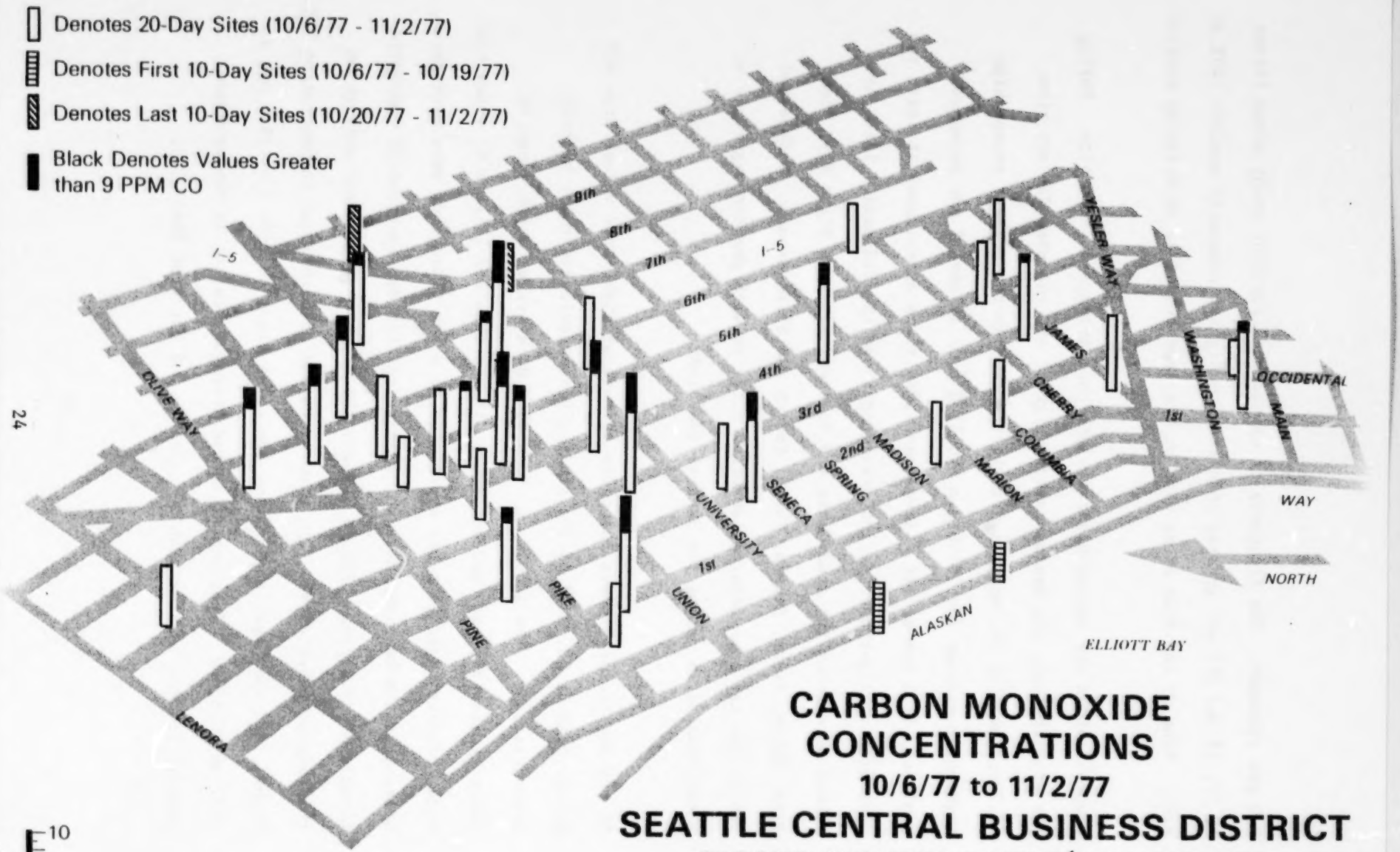
* On this day, data for site 9, which was nearly collocated with the permanent monitor (PIK), indicated 12.4 ppm - 3.4 ppm less than at PIK. However, this was atypical in that on most days data from the two sites were within 1 ppm.

9.0 ppm standard. The frequency of exceedences for four study sites (sites 7, 17, 19 and 36) was greater than for the highest permanent monitor (40% at PIK). None of the four sites were on the same street as an existing monitor.

Figure 5 shows the second-highest eight-hour average at each site. During the study period, the maximum second-highest AVC recorded for any site, 13.5 ppm at site 19, was essentially the same as the highest second-high eight-hour average for 10:00 a.m. to 6:00 p.m. at any of the permanent monitors, 13.6 ppm at PIK. Seventeen study sites experienced at least two days with an eight-hour period averaging above the standard. These were spread throughout the study area and included sites on Olive Way, Pine, Pike, Union, First, Second, Third, Fourth and Sixth Avenue. Undetected violations may have occurred at other sites or with greater magnitude at these same sites during the days of the study.

On the day of the highest composite average of eight-hour values from all sites, October 28, half of the study sites experienced their highest concentrations. The 10:00 a.m. to 6:00 p.m. average carbon monoxide concentration for each outdoor study site on this day (Figure 6) shows that high concentrations were not restricted to a few sites, but were widespread. Sixteen of the twenty-nine sites sampled on this day experienced concentrations above 9.0 ppm. (Figure 7 shows the range of eight-hour average on this and on other days). One study site had an eight-hour concentration 20% higher than the highest permanent monitor's (16.1 at site 1 vs 13.6 ppm at PIK) on that day. Fourteen sites had averages similar to the permanent monitor (ratios greater than or equal to 0.8 but less than 1.2).

FIGURE 5



CARBON MONOXIDE CONCENTRATIONS

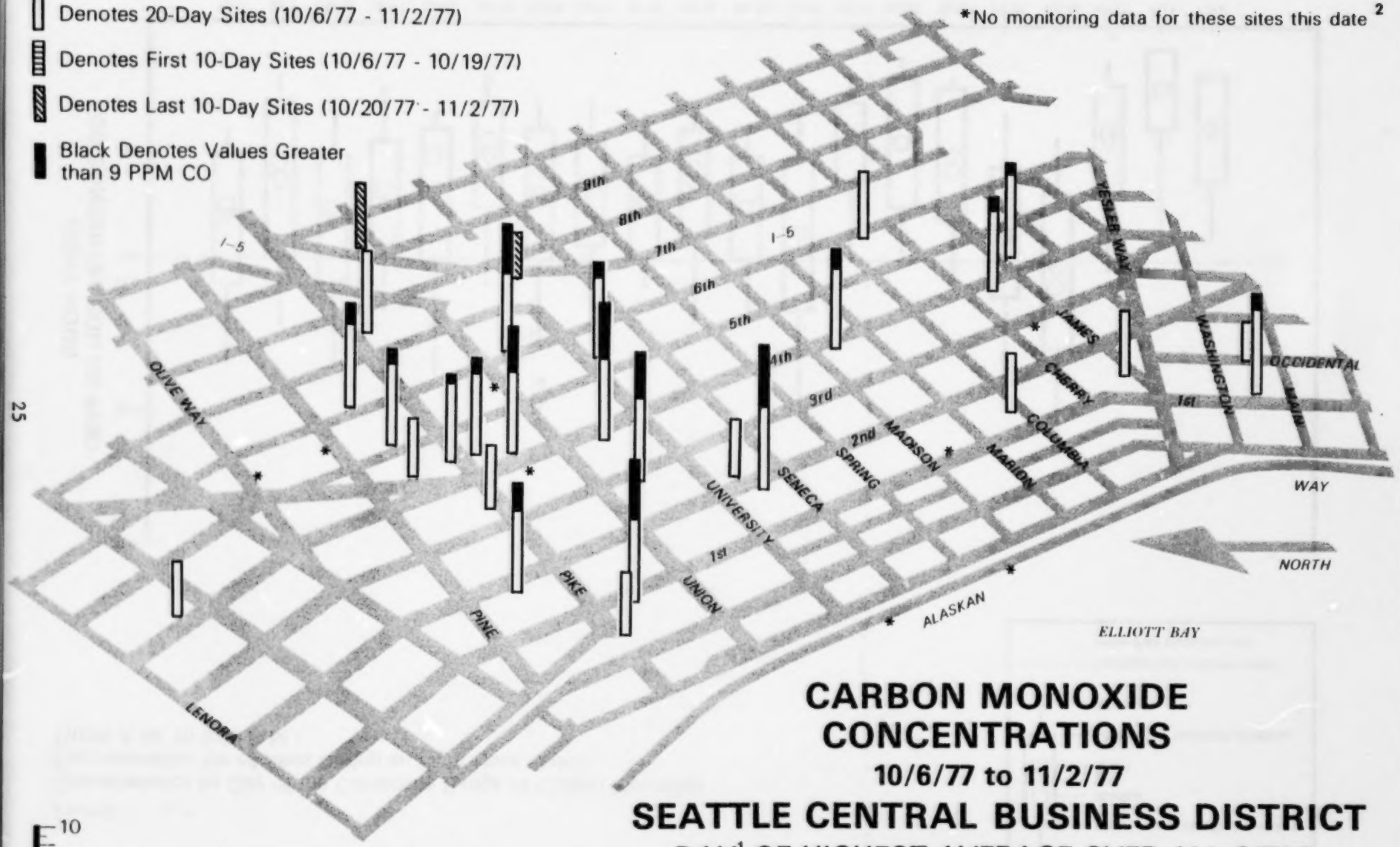
10/6/77 to 11/2/77

SEATTLE CENTRAL BUSINESS DISTRICT

SECOND HIGHEST 8-HOUR[1] VALUES FOR ENTIRE SAMPLING INTERVAL

[1]10AM TO 6 PM

FIGURE 6



CARBON MONOXIDE CONCENTRATIONS

10/6/77 to 11/2/77

SEATTLE CENTRAL BUSINESS DISTRICT

DAY[1] OF HIGHEST AVERAGE OVER ALL SITES

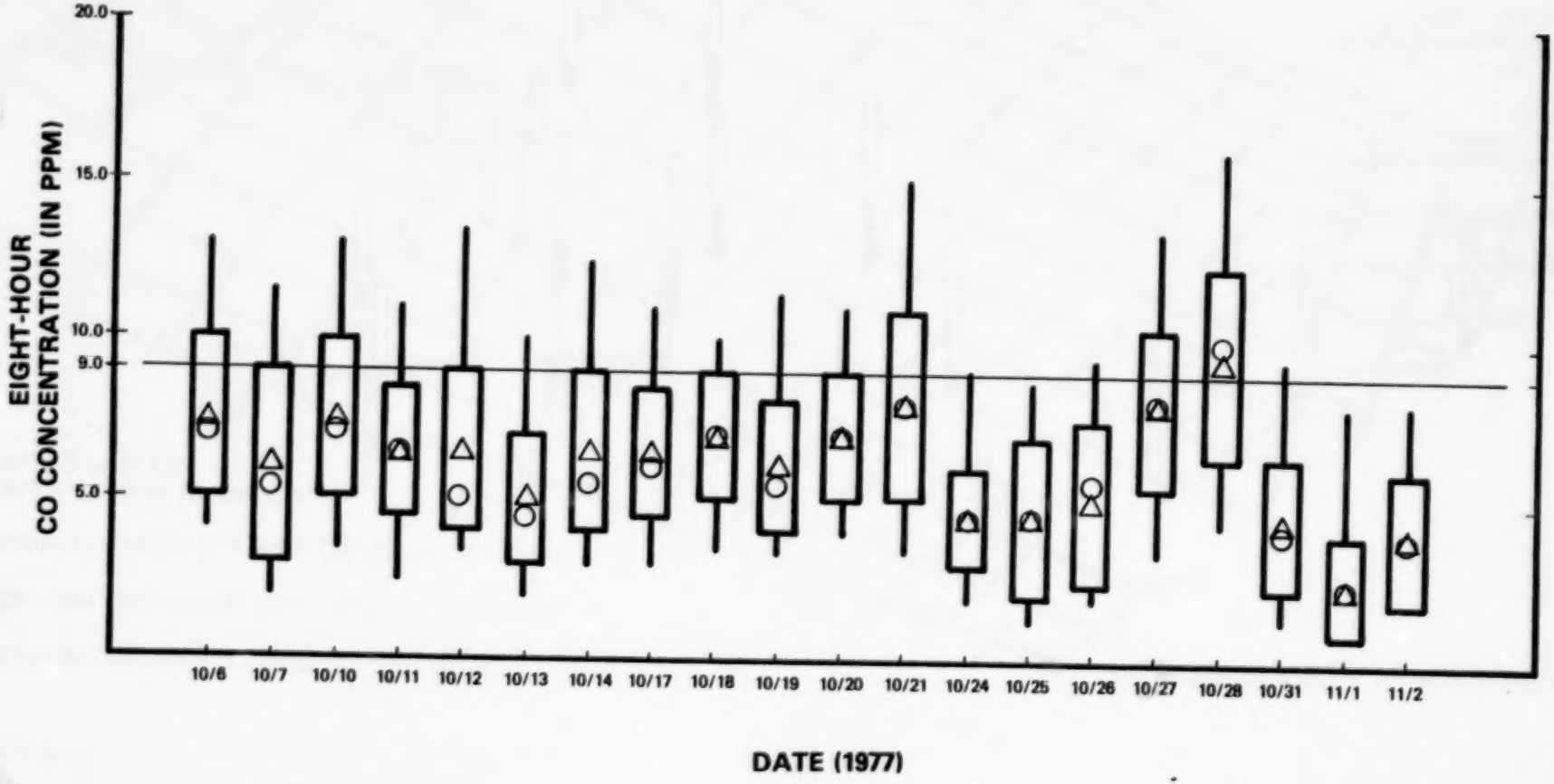
[1]10 AM TO 6 PM

[2]10/28/77

Seattle Carbon Monoxide
October 6 to November 2, 1977

FIGURE 7

Characteristics by Day of the Composite Range of Carbon Monoxide Concentrations for all Sites During an Eight-Hour Period. (10:00 A.M. to 6:00 P.M.)



On four of the days when no violations were observed at the permanent monitors,* the maximum concentration at a study site was above 9.0 ppm and more than 1.5 times greater than the highest concentration observed at a permanent monitor. However, a concentration above 9.0 ppm at any of the permanent monitors was usually accompanied by equally high or higher concentrations elsewhere. The highest concentration for 10:00 a.m. to 6:00 p.m. at the permanent monitors was higher than at any other site on only two days of the study (Table 3).

Indoor Sites

At all five indoor sites, the concentrations were nearly always less and never more than 1 ppm greater than at the adjacent outdoor sites. At one site (the first floor retail shop), the indoor CO concentration was usually within one ppm of the outdoor concentration. Otherwise, no consistent relationship between indoor and outdoor levels was noted in this limited study. The eight-hour average concentration between 10:00 a.m. to 6:00 p.m. exceeded 9.0 ppm at one of the indoor locations with a maximum value of 10.1 ppm. At this site, late afternoon increases in indoor CO were observed, suggesting an influence from the afternoon peak traffic.

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* On three of these days, data were incomplete for three or four of the five permanent monitors.

TABLE 3. Comparison of Maximum Study Site Each Day and Permanent Monitors by Eight-Hour Averages for 10:00 a.m. to 6:00 p.m.

(CO in ppm)

1977 Date	Max Study Site	Max AVC	Max Perm Mon	Max AVS [1]	Ratio [2] AVC/AVS	Ratio AVC/JAM	Ratio AVC/UNI	Ratio AVC/SIN	Ratio AVC/PIK	Ratio AVC/FIR
10/06/77	19	12.9	UNI	10.6	1.2	2.1	1.2	1.4	1.3	2.1
10/07/77	1	11.6	JAM	6.4	1.8	1.8	2.0	1.9	2.4	3.3
10/10/77	7	12.9	JAM	9.1	1.4	1.4	1.8	1.9	-	2.6
10/11/77	9	11.2	PIK	13.3	.8	1.1	1.4	1.5	.8	3.7
10/12/77	19	13.5	PIK	8.5	1.6	3.3	-	-	1.6	-
10/13/77	19	10.2	PIK	9.9	1.0	1.1	2.7	1.7	1.0	-
10/14/77	19	12.8	PIK	15.8	.8	1.1	2.0	2.2	.8	-
10/17/77	36	11.1	UNI	4.9	2.3	-	2.3	-	-	-
10/18/77	7	10.2	UNI	7.3	1.4	1.5	1.4	1.8	1.7	-
10/19/77	19	11.5	PIK	11.5	1.0	1.1	2.6	1.9	1.0	-
10/20/77	19	11.3	UNI	8.9	1.3	1.6	1.3	.0	1.3	1.9
10/21/77	10	15.0	PIK	12.0	1.2	3.1	1.4	1.5	1.2	-
10/24/77	22	8.9	PIK	8.0	1.1	2.6	1.7	1.4	1.1	3.4
10/25/77	19	8.7	FIR	2.6	3.3	-	-	-	-	3.3
10/26/77	19	9.5	PIK	9.4	1.0	-	1.2	1.4	1.0	2.6
10/27/77	5	13.7	SIN	8.6	1.6	-	-	1.6	1.8	-
10/28/77	1	16.1	PIK	13.6	1.2	-	1.3	1.3	1.2	2.5
10/31/77	22	9.5	PIK	8.3	1.2	-	1.6	1.4	1.2	3.5
11/01/77	29	8.1	PIK	4.6	1.8	-	2.3	-	1.8	4.6
11/02/77	10	8.1	PIK	7.3	1.1	-	1.7	1.4	1.1	3.6

1. Where AVS is the maximum eight-hour value (10:00 a.m. to 6:00 p.m.) of those for the five permanent monitors in the central business district.

2. Ratio of the maximum study site eight-hour value (10:00 a.m. to 6:00 p.m.) to the maximum of the permanent monitors.

Pedestrian Data

Sampling periods ranged in length from about two to four hours on two routes which varied from day to day. For these samples, concentrations ranged from 1.1 ppm to 11.9 ppm. On some days, the average carbon monoxide for a four-hour period may exceed 9.0 ppm for a pedestrian. Correlations between concentrations on Route A and those on Route B on the same day were better than between morning and afternoon samples from the same route.